

SUPERSYMMETRY WITHOUT UNIVERSALITY: CP VIOLATION AND MIXING IN B MESONS

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We study flavour physics and CP violation in the context of low energy Supersymmetry with non-universal soft mass terms for sfermions. Large deviations from Standard Model predictions are allowed in B-physics, as shown in two explicit examples. In particular, the consequences of these models for $a_{J/\psi K}$ and Δm_{B_s} are worked out.

1 Introduction

The first measurements of the time-dependent CP asymmetries in the decays $B \rightarrow J/\psi K$ ($a_{J/\psi K}$) marked the starting point of a long experimental program to be carried on in next years with the aim of pushing our knowledge of flavour physics in the hadronic sector to the highest precision, in particular for CP violating observables in B-meson physics. In the Standard Model (SM) all flavour and CP violation physics is controlled by the Cabibbo-Kobayashi-Maskawa unitary matrix (CKM), that can be parametrized in terms of three mixing angles and just one complex phase. Unitarity relations of the CKM can be translated in a graphical representation in the $(\bar{\rho}, \bar{\eta})$ plane¹ (Unitarity Triangle, UT). At present the UT is reconstructed from the measured values of ε_K (CP-odd), $|V_{ub}/V_{cb}|$ and Δm_{B_d} (CP-even), and from the lower limit on Δm_{B_s} . This allows to give definite predictions for observables related to the angles of the UT, and it is in principle possible to use this tool in the (indirect) search for new physics affecting flavour physics, thanks to the fact that $\Delta F = 2$ observables can receive large contributions from virtual exchange of new heavy particles in loop dominated processes. Especially those observables that are theoretically clean (i.e. free from large hadronic uncertainties), as $a_{J/\psi K}$ is, could deviate in sizable ways from the SM predictions, signaling an inconsistency in the pure SM Unitarity Triangle analysis. This would be a first evidence for new physics before LHC starts operating, in particular for Supersymmetry (SUSY), which seems to be the most promising

extension of Standard Model with interesting low energy features. In spite of this, it has been understood that without a completely new flavour structure in the soft terms of the SUSY Lagrangian it is very unlikely to have such a clear signature: for large classes of supersymmetric models with no new sources of flavour violation (C-MSSM for example) the deviations of CP-odd observables from SM prediction are so small² that the experimental precision reachable makes very difficult to detect them.

We construct two explicit examples³ of supersymmetric extensions of SM with non-universal soft terms, in which large deviations are predicted from the standard UT, while a dynamical motivation is provided for the peculiar flavour structure needed in the sfermionic sector to avoid exceedingly large contributions to Flavour Changing Neutral Current (FCNC), that could arise in a general SUSY model. In both these models we are allowed to work with Mass Insertion Approximation (MIA) and we focus our attention on soft sfermion masses neglecting the effects of the LR insertions, that we assume to be very small, in order not to exceed bounds coming from EDMs, ε'/ε and $b \rightarrow s\gamma$ transitions.

2 Non-universal singlet masses

As a first example, we consider a model inspired to Type-I string theory⁴. Squark doublets have universal masses, while singlets have not:

$$\begin{cases} (\tilde{m}_Q^2)_{ii} &= m_{3/2}^2(1 - \frac{3}{2}\cos^2\theta(1 - \Theta_1^2)) \\ (\tilde{m}_d^2)_{ii} &= m_{3/2}^2(1 - 3\cos^2\theta\Theta_i^2) \end{cases} \quad (1)$$

θ and Θ_i are goldstino angles, that we can treat as free parameters, and $m_{3/2}$ is the gravitino mass. In the basis where squarks are diagonal $V_{CKM} = (V^U)^\dagger V^D$, being $V^{U,D}$ the unitary matrices rotating left fields in the diagonalization of the Yukawa couplings. Let us assume that V_{CKM} is real (extreme situation, not realistic) and that the $V^{U,D}$ matrices have the same structure as the CKM one (conservative assumption). The re-phasing needed to make the CKM real leaves a set of new observable phases in the $V^{U,D}$ matrices (denoted here φ_i , $i = 1, \dots, 3$), which will appear in the expression of the mass insertions, written in the basis in which fermions are diagonal:

$$V^D \simeq \begin{pmatrix} 1 - \lambda^2/2 & \lambda e^{i\varphi_1} & A\lambda^3 e^{i\varphi_2} \\ -\lambda e^{-i\varphi_1} & 1 - \lambda^2/2 & A\lambda^2 e^{i\varphi_3} \\ A\lambda^3 (e^{-i(\varphi_1+\varphi_3)} - \rho e^{-i\varphi_2}) & -A\lambda^2 e^{-i\varphi_3} & 1 \end{pmatrix}, \quad (2)$$

$$(\delta_{RR}^d)_{ij} = \frac{1}{\tilde{m}_q^2} \left((\tilde{m}_{d_2}^2 - \tilde{m}_{d_1}^2) V_{i2}^D V_{j2}^{D*} + (\tilde{m}_{d_3}^2 - \tilde{m}_{d_1}^2) V_{i3}^D V_{j3}^{D*} \right). \quad (3)$$

λ , ρ and A are the parameters of the Wolfenstein parameterization of CKM¹. After the SUSY running down to the electroweak scale (in the hypothesis of gluino dominance), we find:

$$\Im(\delta_{RR}^d)_{12} \simeq \frac{\cos^2\theta(\Theta_1^2 - \Theta_2^2)}{7\sin^2\theta} \lambda \sin\varphi_1 \quad (4)$$

$$\simeq 0.03(\Theta_1^2 - \Theta_2^2) \sin\varphi_1 \lesssim 0.0032, \quad (5)$$

for $\sin\theta \sim 0.7$. So it is possible to fully saturate ε_K with SUSY. On the contrary the 13 insertion turns out to be proportional to $A\lambda^3/6 \sim 10^{-3}$, while the saturation limit from B physics is around 0.098⁵. This means that SUSY contributes negligibly to B_d mixing, the UT collapses to a line due to the vanishing of the phase in the CKM, and $a_{J/\psi K}$ is predicted to vanish. Actually this is not compatible with CP-even observable measurements, that predict a non-zero phase in the CKM, which could however be much smaller than the one predicted by Standard UT (in which ε_K plays a crucial role). Values as low as $a_{J/\psi K} \sim 0.2 \div 0.3$ could be accommodated, still satisfying all other possible experimental constraints.

3 Non-abelian flavour symmetries

To have a sizable contribution to B -meson oscillation parameters, without exceeding the bounds coming from the $K^0 - \bar{K}^0$ system, one can impose a flavour symmetry to forbid large 12 insertions. This is what happens in a class of supersymmetric models with non-abelian horizontal flavour symmetry, such as $U(2)$ or $SU(3)$. These models gave rise to a lot of interest in recent years due to the constraints they impose on fermionic mass matrices, which allow to fit the UT, giving predictions compatible with experiments for a large variety of observables, both in the hadronic and in the leptonic sector of the SM, in particular for realizations embedded in Grand Unified Theories (GUT) ⁶. In the context of Supergravity mediated SUSY breaking, these symmetries impose analogous constraints also on the sfermionic textures, that can give important contributions to both kaon and B-meson physics (for $\Delta F = 2$ observables), changing drastically the fit of the UT based only on fermionic textures. This would lead to large deviations from SM for the B_s mass difference, and for the time dependent CP asymmetries in $B_d \rightarrow J/\psi K$. As an instance of this, let us consider a model based on $SU(3)$, very similar to others discussed in the literature ⁷. In such a model $SU(3)$ is broken by the vacuum expectation values (VEVs) of a set of SM singlets (flavons) carrying $SU(3)$ quantum numbers, and matter fields are assigned to transform as a triplet. Symmetry breaking is communicated to matter through heavy degrees of freedom, resulting in suppression factors for the couplings proportional to the ratio between the VEVs and this heavy mass scale. In our specific case, we find that the textures for hadronic matter fields, neglecting small higher order terms, are the following (at GUT scale):

$$M_d = m^D \begin{pmatrix} 0 & \epsilon' & 0 \\ -\epsilon' & c\eta & b\epsilon \\ 0 & \epsilon & \eta \end{pmatrix} \quad \begin{aligned} \tilde{m}_Q^2 &= m_{3/2}^2 \begin{pmatrix} 1 & 0 & \alpha\epsilon\epsilon' \\ 0 & 1 + \lambda\epsilon^2 & \beta\epsilon\eta \\ \alpha^*\epsilon\epsilon' & \beta^*\epsilon\eta & r_3 \end{pmatrix} \\ \tilde{m}_d^2 &= m_{3/2}^2 \begin{pmatrix} 1 & 0 & \alpha'\epsilon\epsilon' \\ 0 & 1 + \lambda'\epsilon^2 & \beta'\epsilon\eta \\ \alpha'^*\epsilon\epsilon' & \beta'^*\epsilon\eta & r_3 \end{pmatrix} \end{aligned} \quad (6)$$

Here $c \simeq m_c/m_t$, $r_3 \equiv \tilde{m}_3^2/\tilde{m}_1^2$ is the ratio between the masses of third and first family ($SU(3)$ breaking is large), m^D is proportional to the mass of the bottom quark, while $1 > \eta > \epsilon > \epsilon'$ are suppression factors due to symmetry reasons. The other coefficients are $\mathcal{O}(1)$ couplings, apart from b which can be small due to the presence of the adjoint representation flavon. Up-type mass matrices are assumed to be diagonal.

The structure of the fermionic textures is such that the Jaroskog determinant ⁸ is small: a first prediction of such a model is that the phase in the CKM can be neglected, assuming all parameters entering fermionic matrices to be real. In this way the UT degenerates to a line and the best fit of the fermionic textures to the masses of quarks, and to the elements of the CKM determined by tree level processes ($|V_{ub}|$, $|V_{cb}|$ and $|V_{us}|$), is obtained with $\bar{\rho} < 0$. This leads to a SM contribution to $\Delta m_{B_d} \sim 1 \text{ ps}^{-1}$, a factor of two larger than the experimental value (SUSY and NLO-QDC running are included), so requiring a large SUSY contribution.

Then we compute the mass insertions and the $\Delta F = 2$ amplitudes. We perform a scanning of the parameter space available, imposing the experimental values of ε_K and Δm_{B_d} , and extract the prediction for Δm_{B_s} and $a_{J/\psi K}$. In doing this we notice that not all the free parameters are really relevant for the analysis itself: α and α' could be safely neglected, while loop factors make only a combination of β and β' to be important. In particular this causes a certain degree of correlation between the SUSY contributions to B_d and B_s mixing. All experimental constraints are satisfied, and we find that large discrepancies from the SM ⁹ are possible in large samples of the parameter space. In particular the model allows for every possible value of the time-dependent CP asymmetries, also in $B_s \rightarrow J/\psi\phi$.

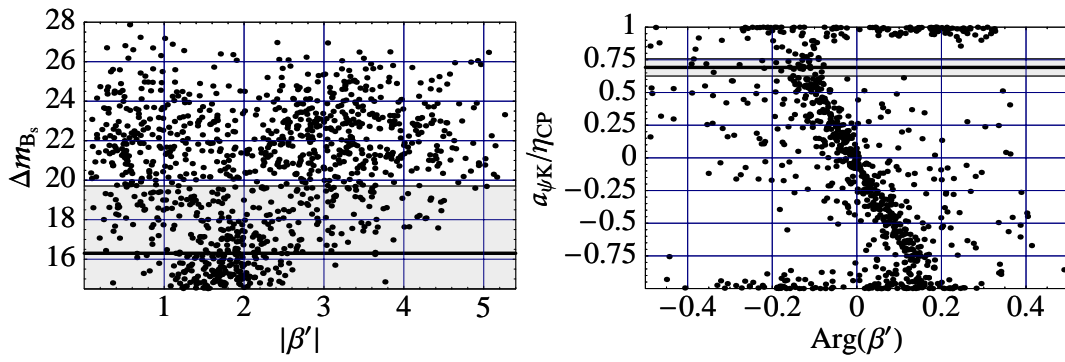


Figure 1: Scatter plots in $SU(3)$ model, compared to SM predictions (in grey) .

Analogous results can be obtained in other models, based for instance on a $U(2)$ symmetry, although the reality of the CKM is quite a peculiar feature, that needs strong constraints on the couplings of the model.

4 Conclusions

Non-universal realizations of SUSY can give large contributions to $\Delta F = 2$ observables, making them distinguishable from SM and making possible an indirect discovery of SUSY in precision measurements in B-meson physics. In particular CP violation could receive large, or even dominant contributions from non-universal SUSY. A realistic model, in which B-physics is strongly affected by SUSY, needs a non-trivial flavour structure, that can be provided by non-abelian flavour symmetries, where the effect of the sfermionic sector must be taken into account in the UT fit.

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